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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : B28B 3/20

A1

(11) International Publication Number: WO 96/01726

(43) International Publication Date: 25 January 1996 (25.01.96)

(21) International Application Number: PCT/DK95/00296

(22) International Filing Date: 7 July 1995 (07.07.95)

(30) Priority Data:
0830/94 8 July 1994 (08.07.94) DK

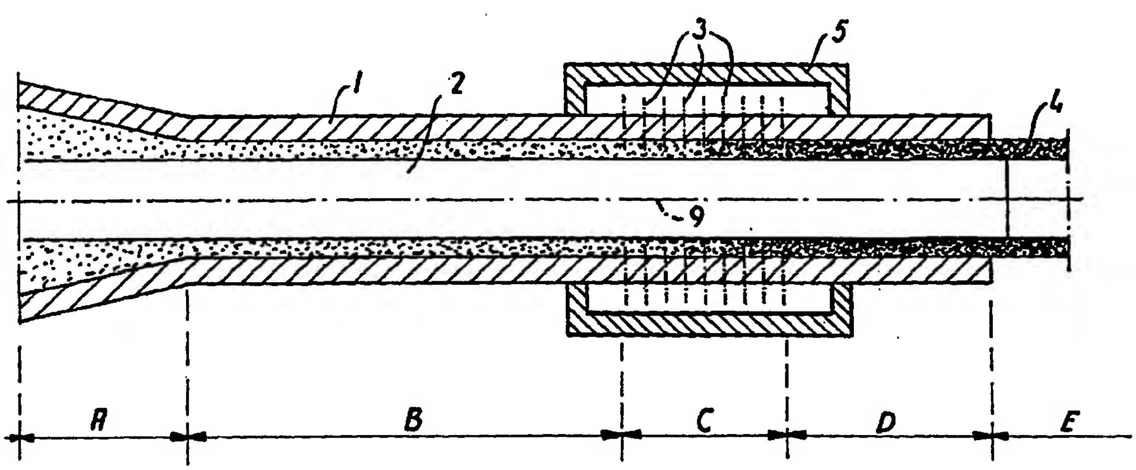
(71)(72) Applicants and Inventors: KRENCHEL, Herbert [DK/DK]; Sundvænget 55, DK-2900 Hellerup (DK). FREDSLUND-HANSEN, Helge [DK/DK]; Fortvej 20 D, DK-2610 Rødovre (DK). STANG, Henrik [DK/DK]; Langebjerg 80, DK-2850 Nærum (DK).

(74) Agent: BUDDE, SCHOU & CO. A/S; Sundkrogsgade 10, DK-2100 København Ø (DK).

(81) Designated States: AM, AT, AU, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LT, LU, LV, MD, MG, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TT, UA, UG, US, UZ, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG), ARIPO patent (KE, MW, SD, SZ, UG).

Published
With international search report.

(54) Title: METHOD AND APPARATUS FOR PRODUCING BODIES OF CONSOLIDATED PARTICULATE MATERIAL, AND PRODUCT PRODUCED THEREBY



(57) Abstract

Shaped bodies of BMC (Brittle Matrix Composite) material produced by introducing an easily flowable slurry of water and particulate BMC material into a mould with perforated walls and applying a sufficiently high pressure to the slurry in the mould so as to express a sufficient proportion of the liquid to allow physical contact and interengagement between the particles. In a special embodiment, the method may be carried out continuously in an extension process comprising (A): introducing the slurry under high pressure, (B): conveying the slurry through a shaping section to (C): a draining and consolidation section with drain holes or slits (3), to leave the extruder through (E): an exit section in the form of a solid body (4).

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METHOD AND APPARATUS FOR PRODUCING BODIES OF CONSOLIDATED PARTICULATE MATERIAL, AND PRODUCT PRODUCED THEREBY

TECHNICAL FIELD

The present invention relates to a method of the kind set forth in the preamble of claim 1.

BACKGROUND ART

In methods of this kind it is known to form and mould so-called BMC material (Brittle-Matrix-Composite material) from a suspension of the particle system concerned in water or other fluent medium.

The particle system may consist of a powder with a certain particle-size distribution, but in many cases it will also comprise fibres, in the end product intended to act as a reinforcement to improve the properties of the finished composite material, especially with regard to strength, toughness and durability.

The BMC material may be a material based on clay, after mixing and moulding to be dried and fired (tiles, bricks, drainpipes and the like), but it may also be a cementitious material (cement, fibre cement, concrete or fibre concrete), which after being mixed and cast in a mould sets and solidifies (within some 2-8 hours), so that it may now be removed from the mould without being deformed, after which it hardens through the chemical reaction between the cement and part of the water in the pores (hydratization).

The material may also consist of hydrated lime and silica mixed with water ($Ca(OH)_2 + SiO_2 + H_2O$), after casting

being autoclave-hardened (temperature 150-220°C), calcium silicate being formed in this process. Finally, the material may consist of gypsum, after casting in the mould setting in the normal manner by taking up water of crystallization.

A common feature of all this materials is that their starting material consists of an inorganic particle system, normally in the form of a relatively fine-grained powder, although in certain cases - such as concerning concrete and fibre concrete - they may also contain coarser particles. In order to bring these materials in a condition, in which they may be shaped and cast, they are mixed with a certain quantity of liquid, normally water, so as to form a paste-like suspension or a slurry of the particle system with the admixed liquid occupying practically all interspaces between the particles. By attuning the amount of liquid relative to the amount of solid particles, it is possible to adjust the viscosity or flowability of the suspension, so as to make it suitable for mixing and casting in a fully homogeneous state to fill out the mould completely. If the proportion of liquid is too small, the flowability of the suspension will be insufficient, so that air pockets may be formed or not all the nooks and crannies of the moulding space will be filled. On the other hand, the proportion of liquid must not be too high, as this will cause the end product to become too porous and hence both weak and brittle.

Further, there is one more complication: in order to achieve the best possible mixing of the starting ingredients with practically 100% homogenization of the solid components (fine particles, fillers and additives),

essential for optimum material proporties in the end product, it is necessary to work with a relatively high ratio of liquid to solid matter, preferably considerably higher than required to achieve good casting proporties. This applies especially when the material contains a suitable quantity of long and thin fibres, because the amount of liquid necessary for the complete splitting-up and dispersion of fibres in such a particle system is considerably greater than for similar mixes without fibres depending primarily on the volume concentration of bribre.

On the other hand, it is of decisive importance that the liquid content in the material having been shaped is as low as at all possible, since the end product in that case will have such a low porosity and high strength and toughness as possible.

These two conflicting views with regard to the choice of the magnitude of the liquid proportion will especially be in high mutual contrast in the case of producing fibre--reinforced BMC materials, since it is necessary to use a considerable amount of surplus liquid to achieve a total distribution of the fibres, but on the other hand, the fibres will be of little or no use in the end product, because the bond between the fibres and the highly porous matrix material will be practically equal to zero.

In the production or so-called FRC material (Fibre-Reinforced Cementitious Material), e.g. in the form of asbestos cement or cellulose cement, the problems referred to above are normally solved by first mixing cement and fibres with a great surplus of water (typically 2-10 times as much water as the weight of the cement powder

and fibres), until all fibres are dispersed and the cement particles are evenly distributed on the surfaces of all fibres as a thin coating. During a subsequent dewatering, e.g. on a filter web, completed by removing part of the surplus water by vacuum treatment, sheet-formed and plate-formed objects are formed, and this may be done without disturbing the effective homogenization achieved prior to the dewatering, because the extremely fine cement particles possess a natural affinity to the surface of the thin asbestos or cellulose fibres, so that no "de-homogenization" occurs when the surplus water is removed from the mix.

After this first dewatering on the filter web, the sheet material having been formed is normally sufficiently coherent to be removed from the substrate and placed onto plane (oil-lubricated) steel plates for setting and hardening. The FRC sheets are, however, - as long as the cement is not yet completely hardened - still fully plastic, so that within the next hour or so, they could still be shaped into corrugated sheets or into bodies of even more complicated shape (in the asbestos-cement industry, this stage in the process is referred to as one, in which plastic shaping is possible).

Before the cement begins to set, it is also possible to improve the density and other properties of the end product by means of a "post-pressing" (between steel platens) causing additional removal of part of the surplus water along the free edges of the FRC sheets (pressure 100-200 bar, typical water/cement ratio approximately 0.25 in the sheet material just having been dewatered by vacuum treatment, reduced to approximately 0,15-0.20 after "post-pressing"). Of course, such post-pressing

should, however, be carried out with a gentle raise in pressure (from zero to maximum within 30 minutes or so) in order to prevent that the surplus water now being squeezed out along the plane of the sheets towards its free edges will burst and destroy the shaped sheet, and it will be understood that such a process will under all circumstances result in an FRC product with "woolly" and indistinct edges.

In the case of other materials than asbestos cement or cellulose cement, such as several materials with other types of reinforcement fibres (steel, glass, carbon, polypropylene, polyethylene or other types of synthetic fibres), it should be noted that these types of fibre do not possess the natural affinity to ("buoyancy" for) the cement grains referred to above, for which reason a certain "de-mixing" with fibre surfaces being laid bare during the dewatering process is practically unavoidable with the traditional methods of production and dewatering.

Disclosure of the invention

It is the object of the present invention to provide a method of the kind referred to initially, with which it is possible to avoid the disadvantages referred to above, and this object is achieved with such a method, according to the present invention being characterized by the features set forth in the characterizing clause of claim 1. When proceeding in this manner, the solid components are mixed with as much water as necessary to achieve a total dispersion of all components in the mixture.

If the squeezing-out of the liquid occurs at the same time over the whole surface of the mould, there is a risk

that dewatered and un-dewatered material moves about uncontrollably in the moulding space with the result that the end product does not become fully homogeneous. This disadvantage may be avoided by proceeding as set forth in claim 2.

When proceeding in this manner, the final part of the pressing process, when no further water may be squeezed out, can be characterized as powder pressing.

Thus, the process as such commences in the form of high--pressure slurry pumping in one end of the mould and terminates as a powder-pressing process steadily progressing from the other end of the mould. It will be understood that in this case, the low-viscosity suspension will have no difficulty in flowing out into all nooks and crannies of the mould, and any air having been trapped during the filling-up of the mould will leave the mould cavity through its perforations. The finished press--moulded object will constitute an accurate replica of the internal surfaces of the mould, and since the composite material already has set and solidified in the mould in the same moment as all surplus water has been squeezed out and mutual contact between the solid-matter particles has been achieved, it is now possible to remove the moulded object from the mould immediately - just as with any other powder-pressing method - since this object is now fully rigid and self-supporting and requires no more than being allowed to harden completely in a suitable manner.

Similar results with regard to making the dewatering and consolidation process progress steadily from one end or side of the mould to the other may be achieved by

proceeding as set forth in claim 3 or claim 4.

The perforations holes in the walls of the moulds should, of course, be exstremely fine, so that the water, but not the solid-matter particles may escape from the mould, but since water molecules are extremely small (approximately 20 Å), this should not be a problem.

The en product made by proceeding according to one of the embodiments of the method according to the invention is characterized by being exceptionally dense and with an absolute minimum of porosity and highly homogeneous, and by in the fully-hardened condition to possess valuable physical properties comprising an optimum combination of strength and toughness.

Since, as described above, the mixing process is carried out with an arbitrary surplus of liquid, and the concentration of the material subsequently during the casting or moulding process is increased without "de-mixing" taking place, until no more liquid can be squeezed out from the confined material, it is possible in this case to achieve a considerably higher concentration of fibres in the end product than by using any other known moulding or casting principle, still with the fibres lying fully dispersed and well distributed and oriented throughout the product.

During the terminal part of the pressing process, during which the solid particles are solidly wedged and pressed together, so that the material solidifies, the particles are also pressed firmly against all fibre surfaces - in certain cases even into the surfaces of the fibres- resulting in optimum bond between of the fibre and the

matrix material and hence optimum fibre effect in the end product.

In this process, fibres and matrix material "grow together" in a manner not being known from other casting or moulding processes, and after having fully hardened, the end product possesses unique physical proporties.

With uniaxial tension loading, which is the most problematic form of loading to such brittle-matrix materials (because it is difficult for the fibres to take over the whole tensional load when the matrix), it is possible with a correctly reinforced BMC material produced according to the present invention to achieve a stress-strain curve more reminiscent of the stress-strain curve for a metal or for a plastic material than for an ordinary brittle matrix material normally exhibiting an ultimate elongation at rupture of only approximately 0.01-0.02 per cent (0.1-0.2 mm per m).

After hardening, a correctly made BMC material produced according to the present invention will have a tensile stress-strain curve exhibiting so-called strain hardening, in which the tensile stress continues to increase - without any formation of visible or harmful cracks - even right up to a strain of 1-2% or more. Thus, the strainability (elasticity or flexibility if so preferred) of the matrix material has, by extreme use of the admixed fibres, been increased by a factor of 100 or more - and this without causing any damage to the composite material.

The cause of the dramatically increased strainability is that the internal rupturing of the matrix material

between the fibres due to tensile straining occurs in a different manner than in similar non-reinforced material, as on a microscopic level, an evenly distributed pattern of extremely fine and short microscopic cracks are formed, increasing in number with increased straining of the material; these microscopic cracks are, however, so small that they may be stopped or blocked by the surrounding fibres, and for this reason they cause no dramatic damage to the material as such.

This is in itself extremely valuable and applies in general to the high-quality BMC materials mentioned above as produced by the methods according to the invention. Further, experience has shown that for so-called FRC material produced with a normal Portland-cement matrix, the network of micro-cracks formed in the manner referred to above (with possible lengths of approximately 0.5-1 mm or less, width typically 10-50 μm) after being formed shows a marked tendency to self-healing, so that the material in the presence of moisture will again be dense, and so that the material when again being tension loaded achieves its original rigidity and strength and may be subjected to increased stresses in the same manner as during the first loading, also here exhibiting a smooth working curve and a convincing strain hardening with steadily increasing tensile stresses up to an ultimate straining capacity of 1-2% or more before the stresses begin to decrease.

The present invention also relates to an apparatus for carrying out the method of the invention. This apparatus is of the kind set forth in the preamble of claim 18, and according to the present invention, it also comprises the features set forth in the characterizing clause of

this claim 18.

Finally, the invention relates to a product, such as set forth in claim 30.

Advantageous embodiments of the method and the apparatus, the effects of which - beyond what is self-evident - are explained in the following detailed part of the present description, are set forth in claims 5-17 and 19-29, respectively.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following detailed portion of the present description, the invention will be explained in more detail with reference to the drawings, in which

Figure 1 is a diagrammatic longitudinal sectional view through the parts of an extruder relevant to the invention,

Figure 2 shows an example of the formation of draining openings in the part of the extruder wall constituting the drainage section,

Figure 3 is a sectional view through a ring adapted to co-operate with a number of similar rings to form an extruder wall with draining slits, and

Figure 4 shows a part of an extruder wall composed of a number of rings of the kind shown in Figure 3.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Figure 1 shows the parts of an extruder essential to the invention, specially designed for producing tubular products, it being obvious that an extruder based on the same principles could also be used for extruding products with other cross-sectional shapes, such as flat or corrugated sheets or profiled stock of various cross-sectional shapes.

The parts of the extruder shown comprise an outer part 1, an inner part 2, a plurality of nozzles or slits 3 for draining-off liquid, as well as a pressure-regulating chamber 5.

As shown, the extruder is divided into four consecutive sections, i.e.

- an inlet section A for the supply of flowable suspension to be compacted, and
- a flow section B, in which the suspension having been supplied flows towards
- a drainage and consolidation section C leading into
- a solid-friction section D.

Further, Figure 1 shows a further section, designated the exit section E, in which the extruded product leaves the extruder.

For ease of understanding, Figure 1 shows the above-mentioned sections as quite distinct from each other, but in practice, two or more sections may overlap to a greater or lesser degree. Thus, the nozzles 3, shown in Figure 1 as solely being present in the drainage and consolidation section C, may well also extend along at least a part of the solid-friction section D.

In the inlet section A, a flowable suspension containing the requisite amounts of powder, liquid (normally water) and possibly further components flows into the flow section B. The suspension supplied to the extruder comprises a surplus of water or other liquid, making it possible to achieve a good and homogeneous intermixing of the components of the suspension, that may have a consistency ranging from a thin slurry to a thick paste.

The mixing process may be carried out in a manner known per se, i.e. by using a high-performance mixer producing a paste-like particle suspension with the desired flowability, prior to supplying the latter to the inlet section A of the extruder by means of a high-pressure pump of a type capable of pumping material of this kind.

From the inlet section A, the suspension flows in the forward direction through the flow section B. The cross-sectional shape of the shaped product in this section B and the subsequent drainage and consolidation section C is determined by the internal shape of the outer part 1 and the external shape of the inner part 2. In the drainage and consolidation section C, surplus liquid is drained off, and the suspension is consolidated to form a solid material with direct contact between the individual particles throughout the product, as substantially all surplus liquid, i.e. substantially all liquid not remaining to occupy the interspaces between the closely packed particles in direct mutual contact, is removed. This draining-off function is caused by the pressure differential across the outer part 1 in the drainage and consolidation section C being applied to the nozzles or slits 3. The pressure differential constitutes the difference between on the one hand the hydrostatic pressure in the suspension in the flow section B and part of the drainage and consolidation section C, which may lie in the range of 20-400 bar, and on the other hand the pressure within the pressure-regulating chamber 5, that may be atmospheric pressure or somewhat higher or lower, as will be explained below.

Obviously, the high hydrostatic pressure reigning in the flow section B and at least the adjacent part of the

drainage and consolidation section C can only be maintained, if the part of the extruder downstream of the drainage and consolidation section C comprises some means of obstructing flow. In the method according to the present invention, these means are provided by the non-flowable extruded product resulting from the drainage and consolidation described above, being present in the solid-friction section D. In this section D, the friction between the product 4 and the walls of the outer part 1 and the inner part 2 in contact with it is sufficient to provide a reaction force of substantially the same magnitude as the oppositely acting hydraulic force resulting from the hydraulic pressure upstream of the solid-friction section D. In operation, the supply pressure and the pressure in the pressure-regulating chamber 5 are attuned to each other and to the friction referred to in the solid-friction section D so as to allow the product 4 to advance at a suitable speed.

When the product 4 leaves the extruder in the exit section E, its porosity is extremely low and it contains substantially no more liquid than that occupying the interspaces between the closely packed particles, so that the product 4 has a sufficient dimensional stability to withstand handling during the subsequent processing without being deformed due to its own weight. Such subsequent processing may i.e. be firing in the case of a product containing clay, or hardening in the case of a product based on cement.

When starting-up the process, it is necessary to provide the reaction force referred to above by separate means, as the non-flowable product part has not yet been formed in the solid-friction section D. This may suitably be

achieved by inserting a reaction-force plug (not shown) into the downstream end of the interspace between the outer part 1 and the inner part 2 so as to effect a temporary closure.

As soon as the non-flowable "plug" of consolidated material has been formed in the solid-friction section D, it will normally provide a sufficient reaction force, but will on the other hand, of course, require a considerable force to act upon it to overcome the friction against the extruder walls and move it forward.

With an extruder constructed according to the principle shown in Figure 1, it may not always be possible to attune the pressures referred to above in such a manner, that the consolidated product in the solid-friction section D will be moved, as an increase in the supply pressure, i.e. an increase in the inlet section A and the flow section B, may cause the friction between the consolidated product and the extruder walls to produce a reaction force that will always be too high. The effects of this high frictional force may be reduced in a number of different ways to be explained below.

A first method of reducing the effect of friction between the consolidated material and the walls of the extruder consists in subjecting the exit portion of the extruder or a part of same to mechanical vibrations. The frequence of these vibrations may lie in the interval 10-400 Hz, while the interval 20-200 Hz is preferred and the interval 50-150 Hz is more preferred. A frequency of 50 or 60 Hz or harmonics thereof are particularly advantageous, as they can be produced by connecting the vibrator concerned to an alternating-current mains supply.

Another method of reducing the effect of the high friction referred to above is to subject the flowable suspension upstream of the consolidated product to pressure variations, so that periods with a first, lower pressure alternate with second, shorter periods with a second, higher pressure, said second pressure being approximately 1.5-8, preferably 2-4 times greater than said first pressure.

A third method of reducing the effect of the high friction referred to above is to vary the pressure in the pressure-regulating chamber 5, so that the surface of the product in some periods is subjected to reduced pressure to support the draining-off process, and in other periods being subjected to a high-pressure to reduce the friction between the product and the extruder walls.

A fourth method of reducing the effect of the high friction referred to above is based on using an extruder, in which a first part, i.e. the outer part 1 shown in Figure 1, is capable of being reciprocated in the longitudinal direction relative to another part of the extruder, e.g. the inner parts 2. With such relative movement, that may e.g. be effected by using a crank mechanism (not shown), the product 4 will be made to "walk" stepwise in the downstream direction.

Figure 2 shows one example of how the requisite permeability of the extruder wall in the drainage and consolidation section C may be achieved. Thus, in the outer part 1 a number of holes 6 have been drilled into the outer part 1 from the outside. As shown, the holes 6 only extend to within approx. 1 mm from the inside wall 7. In the latter, a plurality of extremely fine perforations 8 with transverse dimensions of the order of 0.001-0.01 mm extend

through the respective drilled holes 6. The perforations 8 may be produced by means of e.g. spark erosion or by using a laser beam. Figure 2 also shows the central axis 9 of the extruder.

Another way of providing the requisite openings in the drainage and consolidation section C is shown in Figures 3 and 4. Thus, Figure 3 shows a ring to be used for this purpose, and Figure 4 shows how a number of such rings are assembled to form a number of slits constituting said openings.

The ring 12 shown in Figure 3 comprises an inner periphery 10 and an outer periphery 11. The width b_1 of the inner periphery 10 is a trifle, typically approximately 0.001-0.01 mm, less than the width b_2 of the outer periphery 11. Thus, when a number of rings 12 are clamped axially together in the extruder, slits 3 will be formed between them with a width of typically approximately 0.001-0.01 mm in the drainage and consolidation section C, through which the liquid to be drained off may escape.

Figure 4 shows a number of rings 12 of the kind shown in Figure 3 mounted in the axial direction in the outer part 1 of the extruder, so that the inner peripheries 10 of the rings are aligned with the inside surface of the outer part 1 of the extruder. Figure 4 shows the outer parts 1 and a plurality, in this case a total of six, individual rings 12 with the drainage slits 3 between the rings. The central axis 9 of the extruder will also be seen.

LIST OF PARTS

1	Outer part
2	Inner part
3	Nozzle/slit
4	Product
5	Pressure-regulating chamber
6	Hole
7	Inside wall
8	Perforation
9	Central axis
10	Inner periphery
11	Outer periphery
12	Ring
A	Inlet section
B	Flow section
C	Drainage and consolidation section
D	Solid-friction section
E	Exit section
b_1	Width (of 10)
b_2	Width (of 11)

CLAIMS

1. Method for producing shaped bodies of brittle-matrix--composite material by

a) forming a flowable suspension of particulate material in a suitable liquid,

b) introducing said suspension into a moulding space with at least partly liquid-permeable walls,

c) removing at least a major proportion of said liquid by establishing a pressure differential across at least those parts of said walls that are permeable to said liquid, so as to form a non-flowable body of said material, and

d) removing said non-flowable body from said moulding space,

c h a r a c t e r i z e d in

e) that step a above includes homogenization of said suspension so as to form an easily flowable moulding slurry with a ratio between liquid and dry matter of the order of magnitude of 1:1 by weight, and

f) that steps b and c above are carried out by pumping said slurry into a closed mould with finely perforated walls and applying a sufficiently high pressure to the slurry in the mould to express at least a sufficient proportion of the liquid to allow physical contact and interengagement between the particles.

2. Method according to claim 1, c h a r a c t e r i z e d by the use of a mould, in which said perforations are distributed and adapted in such a manner, that said liquid will be expressed first from the parts of the mould situated most distant from the slurry inlet, then from parts of the mould less distant from said inlet,

then from parts still closer to said inlet and so forth, until the complete moulding space is occupied by closely packed and consolidated particulate material forming a compact body with very low porosity.

3. Method according to claim 2, c h a r a c t e r i z e d by the use of a mould, in which the liquid-permeability of said perforations diminishes steadily from the end of the mould most distant from the inlet towards the latter so as to make the removal of the liquid occur at the highest rate at said most distant end and at a steadily diminishing rate when approaching the inlet.

4. Method according to claim 1, c h a r a c t e r i z e d by the use of a mould, in which the perforations may be closed and opened from the outside, the removal of the liquid being carried out by opening the perforations in a sequence beginning at the point in the mould most distant from the inlet and ending at the latter.

5. Method according to claim 1 and comprising passing said suspension through an extrusion duct of substantially constant cross-sectional shape and size and removing liquid from the suspension by means of a pressure differential across parts of walls of the extrusion duct having openings allowing the said liquid but not the particles to leave the extrusion duct so as to convert the suspension to a non-flowable body having a cross-sectional shape corresponding to that of that extrusion duct, c h a r a c t e r i z e d in ,

a) that said pressure differential is established and maintained by applying a high super-atmospheric pressure to the said suspension at or upstream of its entry into the extrusion duct and applying or

permitting a substantially lower pressure to reign on the exit side of said openings, and

b) that said pressure differential and the liquid-outflow capability of said openings are mutually attuned in such a manner that the part of said non-flowable body at any time downstream-most in the extrusion duct engages the walls of the extrusion duct with a frictional force sufficient to withstand said pressure applied to the suspension.

6. Method according to claim 1, c h a r a c t e r i z e d in that said pressure differential and the liquid-outflow capability of said openings are mutually attuned in such a manner, that said frictional force allows said non-flowable body to move in a downstream direction under the influence of said pressure applied to the suspension.

7. Method according to any one or any of the claims 1-6, c h a r a c t e r i z e d by the use of a flowable suspension containing material of the kind referred to as "Brittle Matrix Composite" chosen from materials containing clay, materials based on hydraulic cement, calcium-silicate materials and materials containing gypsum.

8. Method according to any one or any of the claims 1-3, c h a r a c t e r i z e d in that the supply pressure causing surplus liquid to be drained off from the particles to be consolidated lies in the interval 20-400 bar, preferably 50-200 bar, more preferably 50-100 bar.

9. Method according to any one or any of the claims 1-8, c h a r a c t e r i z e d in that the liquid is

drained off through pores or slits with a diameter or width of less than approx. 0.5 mm, preferably below approx. 0.1 mm, more preferably below approx. 0.01 mm, e.g. approx. 0.001-0.01 mm.

10. Method according to any one or any of the claims 5-9, c h a r a c t e r i z e d in that the downstream part of the extruder duct or a part of same is subjected to vibration in order to reduce the effect of friction between the consolidated material and the extruder walls, e.g. at a frequency in the interval 10-400 Hz, preferably 20-200 Hz, more preferably 50-150 Hz.

11. Method according to any one or any of the claims 5-10, c h a r a c t e r i z e d in that the flowable suspension upstream of the drained and consolidated material is subjected to varying pressure, so that periods with a first, lower pressure alternate with shorter periods with a second, higher pressure, said second pressure being approx. 1.5-8, preferably 2-4 times greater than said first pressure.

12. Method according to any one or any of the claims 5, 10 and 11, c h a r a c t e r i z e d in that the surface of the product is subjected to varying pressure from a pressure-regulating chamber surrounding the draining section, said surface e.g. in periods being subjected to reduced pressure to support the draining-off process and in other periods subjected to a higher pressure in order to reduce the friction between the product and the extruder walls.

13. Method according to any one or any of the claims 5 and 10-12, c h a r a c t e r i z e d by the use of an

extruder, in which the shaping part is divided longitudinally into at least two parts, that are reciprocated relative to each other in the longitudinal direction in order to ease the forward movement of the consolidated material.

14. Method according to claim 13, c h a r a c t e r i z e d by the use of an extruder, in which the shaping part is divided longitudinally into two parts, of which one is fixed and the other is reciprocated in the longitudinal direction.

15. Method according to any one or any of the claims 1-14, c h a r a c t e r i z e d by the use of a flowable suspension containing fibres evenly distributed in the suspension as such as well as in the consolidated solid product.

16. Method according to claim 15, c h a r a c t e r i z e d in that the fibres are oriented in a desired manner throughout at least a part of the cross-section of the consolidated product by adjusting the conditions of the introduction and consolidation of the suspension, an introduction through an inlet part of converging cross-sectional shape resulting in a tendency to an axial orientation of the fibres, while an introduction through a tangentially directed inlet part and/or a high degree of consolidation will result in a tendency to a preponderance of tangential orientation of the fibres.

17. Method according to claim 15 or 16, c h a r a c t e r i z e d in that the fibres are chosen from high-strength fibres, such as carbon fibres, cellulose fibres, steel fibres, glass fibres, polyolefine fibres including

polypropylene fibres such as KRENIT[R] fibres, cf. US patent No. 4,261,754, and CRACKSTOP[R] fibres, cf. WO 90/06902, ultra-fine fibres such as "whiskers", said fibres or mixtures of same in each case preferably being adapted to the particle system concerned, and wherein the degree of reinforcement in the consolidated product is 1-15%, preferably 3-10%, e.g. 5-10%, all by volume.

18. Apparatus for carrying out the method according to any one or any of the claims 1-17 and of the kind comprising

a) means for forming a flowable suspension of particulate material in a suitable liquid,

b) means for introducing said suspension into a moulding space with at least partly liquid-permeable walls,

c) means for removing at least a major proportion of said liquid by establishing a pressure differential across at least those parts of said walls that are permeable to said liquid, so as to form a non-flowable body of said material, and

d) means for removing said non-flowable body from said moulding space,

c h a r a c t e r i z e d by

e) means for homogeneizing said suspension so as to form an easily flowable moulding slurry with a ratio between liquid and dry matter of the order of magnitude of 1:1 by weight, and

f) means for pumping said slurry into a closed mould with finely perforated walls and applying a sufficiently high pressure to the slurry in the mould to express at least a sufficient proportion of the liquid to allow physical contact and interengagement between the particles.

19. Apparatus according to claum 18, c h a r a c t e r i z e d in a mould, in which said perforations are distributed and adapted in such a manner, that said liquid will be expressed first from the parts of the mould situated most distant from the slurry inlet, then from parts of the mould less distant from said inlet, then from parts still closer to said inlet and so forth, until the complete moulding space is occupied by closed packed and consolidated particulate material forming a compact body with very low porosity.

20. Apparatus according to claim 19, c h a r a c t e r i z e d in that in said mould, liquid-permeability of said perforations diminishes steadily from the end of the mould most distant from the inlet towards the latter so as to make the removal of the liquid occur at the highest rate at said most distant end and at a steadily diminishing rate when approaching the inlet.

21. Apparatus according to claim 18, c h a r a c t e r i z e d by a mould, in which the perforations may be closed and opened from the outside, the removal of the liquid being carried out by opening the perforations in a sequence beginning at the point in the mould most distant from the inlet and ending at the latter.

22. Apparatus for carrying out the method of any one or any of the claims 5 and 10-17 and comprising an extruder with

a) an inlet section (A) adapted to receive a flowable suspension of solid particles in a liquid and leading to

b) an extrusion duct (B, C, D) of substantially constant cross-sectional shape and size and comprising open-

ings (3,8) allowing the liquid but not said particles of said suspension to escape from the extrusion duct under the influence of a pressure differential across a wall or walls (1) comprising said openings (3,8), and

c) means for supplying said flowable suspension under pressure to said inlet section (A),

c h a r a c t e r i z e d in

d) that said means for supplying the flowable suspension under pressure are adapted to supply said suspension at a high super-atmospheric pressure, and

e) that the walls in the extension duct in at least a section (D) situated substantially downstream of said openings (3,8) have a coefficient of friction with the non-flowable product (4) formed by draining and consolidating said suspension in a section (C) comprising said openings sufficient to form a frictionally formed reaction force substantially capable of withstanding the force produced by the hydraulic pressure in said suspension upstream of the section (C) comprising the openings (3,8).

23. Apparatus according to claim 22, c h a r a c t e r i z e d in that said means for supplying the flowable suspension are adapted to supply said suspension at a pressure in the interval 20-400 bar, preferably 50-200 bar, more preferably 50-100 bar.

24. Apparatus according to claim 22 or 23, c h a r a c t e r i z e d in that said openings (3,8) are constituted by pores or slits with a transverse dimension of less than approx. 0.5 mm, preferably below approx. 0.1 mm, more preferably below approx. 0.01 mm, e.g. approx. 0.001-0.01 mm.

25. Apparatus according to any one or any of the claims 22-24, c h a r a c t e r i z e d in that the downstream part of the extruder duct or a part of same is adapted to be subjected to vibrations at a frequency in the interval 10-400 Hz, preferably 20-200 Hz, more preferably 50-150 Hz.

26. Apparatus according to any one or any of the claims 22-25, c h a r a c t e r i z e d by means for subjecting the flowable suspension upstream of the drained and consolidated material to a varying pressure, so that periods with a first, lower pressure alternate with shorter periods with a second, higher pressure, the second pressure being approx. 1.5-8, preferably 2-4 times greater than said first pressure.

27. Apparatus according to any one or any of the claims 22-26, c h a r a c t e r i z e d by a pressure-regulating chamber (5) surrounding said section (C) comprising said openings and adapted to have different pressures applied in it.

28. Apparatus according to any one or any of the claims 22-27, c h a r a c t e r i z e d in that the shape-providing parts of the extruder are divided in the longitudinal direction into at least two parts adapted to be reciprocated relative to each other in the longitudinal direction.

29. Apparatus according to any one or any of the claims 22-28, c h a r a c t e r i z e d in that the inlet section (A) adapted to receive the flowable suspension under pressure and transfer it to the shape-giving parts (B, C, D) of the extruder has a cross-sectional shape

and size diminishing in the downstream direction.

30. Product consisting of a non-flowable body of consolidated, closely packed particles of solid material, c h a r a c t e r i z e d in that it has been produced by carrying out the method of any one or any of the claims 1-17 and/or by using an apparatus according to any one or any of the claims 18-29.

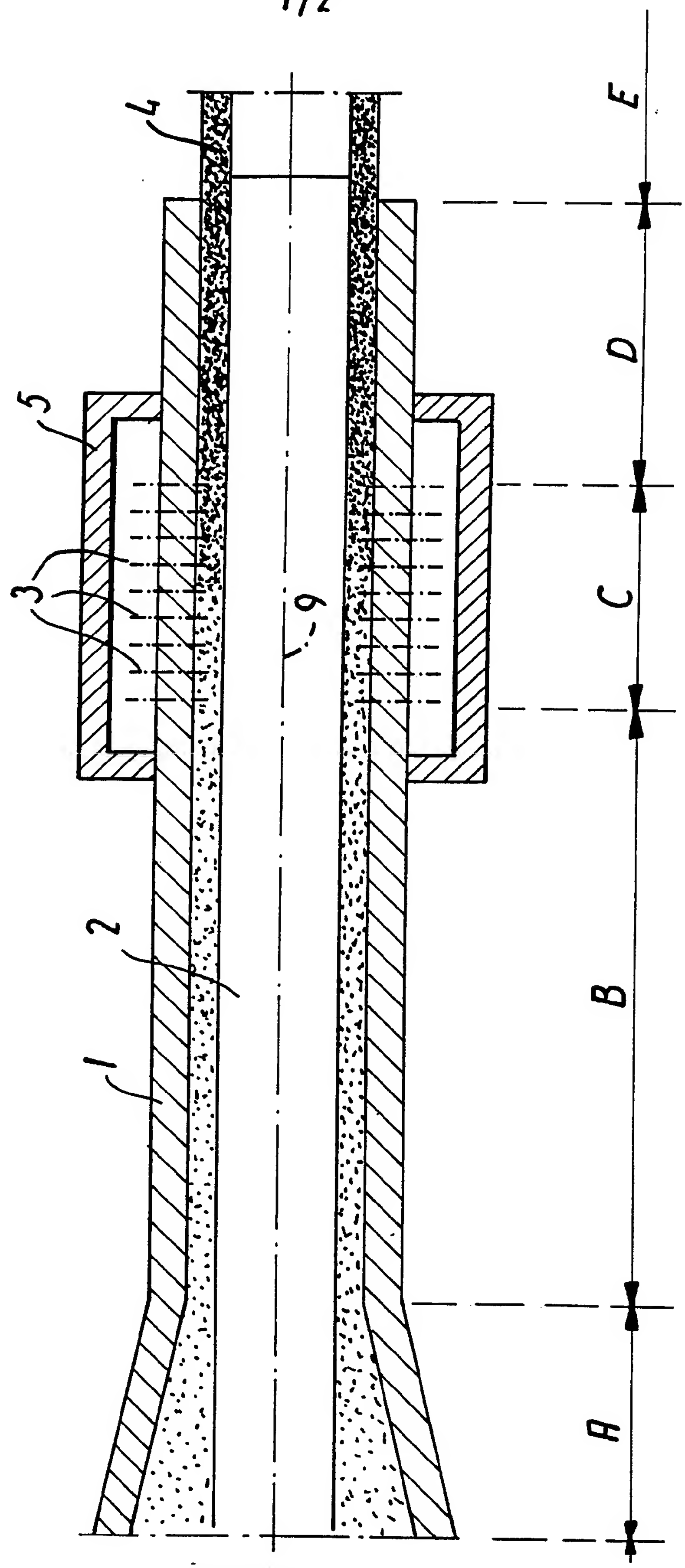

FIG.1

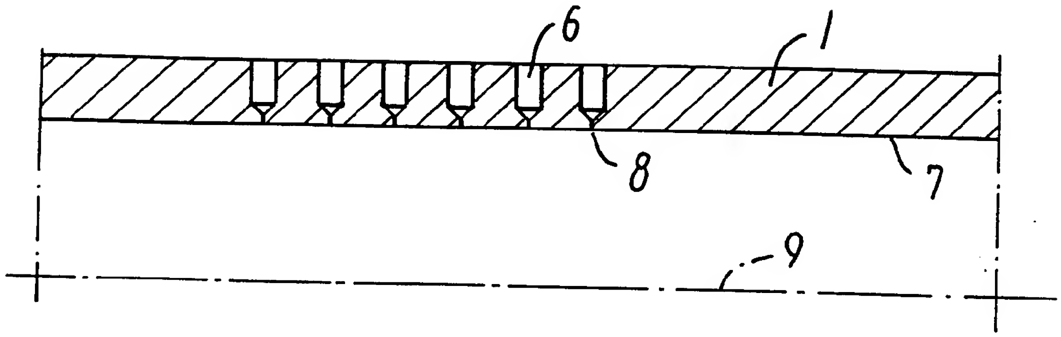

FIG.2

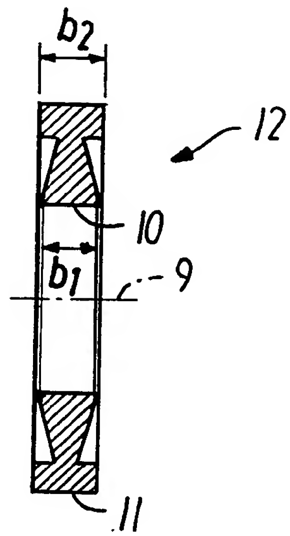

FIG.3

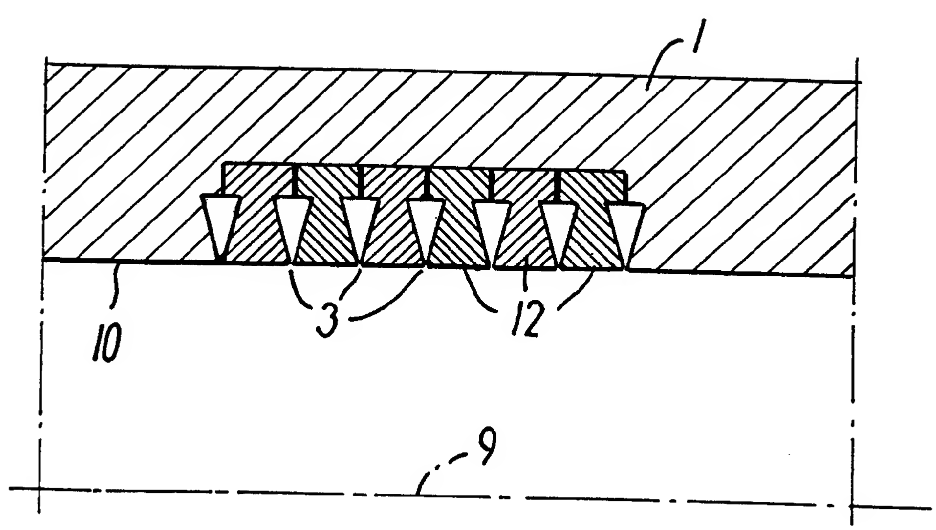

FIG.4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/DK 95/00296

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: B28B 3/20
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: B28B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	SE 304711 B (M.J. ROUVIN ET AL), 30 Sept 1968 (30.09.68), figure 6, claim 1, detail 26 --	1-30
A	DE 954039 C (SIEMENS-SCHUCKERTWERKE AKTIENGESELLSCHAFT), 13 December 1956 (13.12.56), figure 1, claims 1-3, detail 9 --	1-30
A	DE 955210 C (WESSEL-WERK A.-G.), 21 February 1957 (21.02.57), figure 1, claim 1 -- --------	1-30

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" erlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
4 October 1995	12 -10- 1995
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Vilho Juvonen Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

Information on patent family members

28/08/95

International application No.
PCT/DK 95/00296

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
SE-B-	304711	30/09/68	NONE	
DE-C-	954039	13/12/56	NONE	
DE-C-	955210	21/02/57	NONE	